REMARKS

Dr. Michael Morris and Attorney Maurice Klee would like to thank Examiner Angebranndt for the courteous and helpful interview conducted at the Patent and Trademark Office on July 7, 2004. During the interview, advantages of the present invention in the production of convex microlens arrays were discussed.

Submitted herewith is a "Declaration Under 37 CFR §1.132 of G. Michael Morris" (the Morris Declaration). Exhibits B and C to Dr. Morris' declaration are copies of the photomicrophraphs of microlens arrays shown to the Examiner during the interview. Exhibit B shows microlenses produced using the technique of the present invention, while Exhibit C shows a prior art microlens array. Specifically, Exhibit C is an enlarged version of the photomicrograph which appears in Figure 4.11 of the Herzig text (see page 106 of Reference 49 of Applicants' 12/26/01 Modified PTO 1449 Form). As indicated in the legend to Figure 4.11, this microlens array was produced by Dr. Morris' colleagues at Rochester Photonics Corporation.

As explained during the interview, in the prior art such as that of Exhibit C, focused laser beams having small beam widths were used to produce high efficiency microlens arrays. Such small beam widths not only made the process slow, but also led to scan lines in the finished microlenses as can be seen in Exhibit C. Such scan lines scatter light during use of the microlens array, thus deminishing the array's effectiveness.

As illustrated in Exhibit B to the Morris Declaration, the techniques of the present invention avoid the scan line problem, while still producing convex microlens structures which have high fidelity to specified lens profiles and thus high focusing efficiency. Attached as Exhibit D to the Morris Declaration is a reprint of the cover story of the June 2004 issue of Photonics Spectra, which summarizes some of the commercial applications of the techniques of the invention.

As discussed at the interview, in contrast to the prior art, the invention employs relatively large laser beam widths and thus achieves smooth convex microlens surfaces and low scattering. Moreover, by writing the convex microlenses as concave structures

in a positive photoresist, the invention is able to achieve fidelity to specified lens profiles and thus high focusing efficiencies.

The relationship between the shape and size of the laser beam used to write a microlens array and the final surface shape achieved in a photoresist is set forth in equation (1) of applicants' specification as follows:

$$F(x,y) = \iint_S f(x',y')g(x'-x,y'-y)dx'dy', \qquad (1)$$

where f represents the mathematical function describing the desired surface relief, g represents the mathematical form of the writing laser beam, S represents the fabricated surface area, (x,y) denotes a point on the surface of the photosensitive film, and F represents the final surface shape (see applicants' specification at page 9, line 28, to page 10, line 9).

As shown in applicants' Figure 6, a copy of which is reproduced below, when convex microlenses are written in convex form in a positive photoresist, the profile achieved (reference number 62) does not match the desired profile (reference number 61) due to the laser beam's finite beam width:

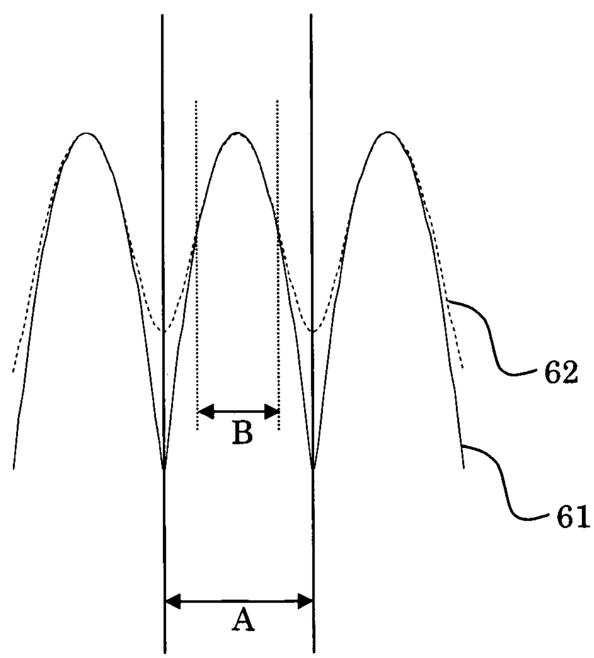

FIG 6

This disparity between curves 61 and 62 results in reduced focusing efficiency, a mathematical expression for which is set forth in equation (2) of applicants' specification as follows:

$$\eta = \left(\frac{B}{A}\right)^2 \times 100\%. \qquad (2)$$

where η is focusing efficiency and A and B are as shown in Figure 6 (see applicants' specification at page 12, lines 3-15).

As discussed at the July 7th interview, applicants discovered that the seemingly irreconcilable problems of low fidelity but smooth surfaces achieved with large beam widths versus high fidelity but scan lines for small beam widths, can be overcome by the the novel approach of the present application in which convex microlenses are written as concavities rather than convexities in a positive photoresist. Figures 7A and 7B of applicants' specification show the remarkable improvement achieved by writing concavities rather than convexities:

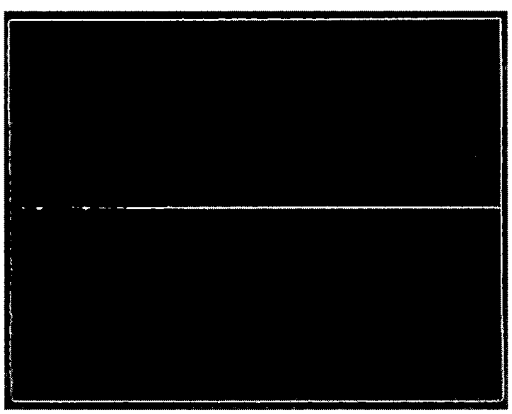

FIG. 7A

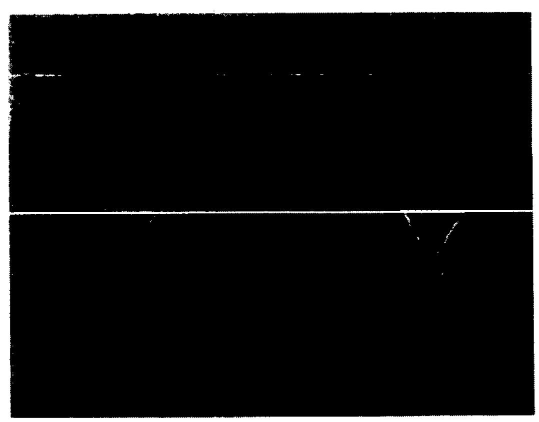

FIG. 7B

As described in applicants' specification, Figure 7A, written as convexities, has an estimated focusing efficiency of only 50%, while Figure 7B, written as concavities, has an estimated efficiency of 100% (see page 12, line 25, to page 13, line 6, of applicants' specification):

> ...FIG. 7A shows the case of an array of microlenses with diameter equal to 50 μm fabricated in convex mode. The boundaries between microlenses are clearly rounded and cannot be efficiently used for focusing. The estimated efficiency for each microlens in this array is 50%.
>
> On the other hand, when the same array is fabricated in concave form one obtains a far better result, as shown in FIG. 7B. Note that the boundaries are preserved. This array is estimated to be 100% efficient in focusing. In addition the concave surface-relief structure can be fully packed without losing efficiency. Direct writing of a convex array cannot achieve such packing without loss of efficiency.

Exhibit E of Dr. Morris' declaration quantifies the predicted changes in focusing efficiency with changes in beam width for a microlens array of the type shown in Figure 7. In preparing this exhibit, equations (1) and (2) were used along with the following standard mathematical form for a Gaussian laser beam

$$g(x) = e^{-8x^2/w^2}$$

where w is the full width of the beam at $1/e^2$.

For f in equation (1), a section of a parabola having a chord of 50 microns and a depth of 25 microns was used based on the 50 micron diameter of the microlenses of Figure 7 and the depth of approximately 25 microns shown in that figure. In equation (2), A was 50 microns and B was taken as the point of 5% deviation between the desired curve (curve 61 in Figure 6) and the final curve (curve 62 in Figure 6), i.e., B was taken as the diameter over which the ratio of the final surface shape F to the desired surface shape f remained above 0.95.

The inserts which appear on the graph of Exhibit E are Figure 6 type plots for representative beam widths of 15, 20, 25, and 30 microns. As can be seen from these inserts, for convex microlenses written in a positive photoresist as convexities, the deviations between desired and final surface shape increase as the beam width increases causing the focusing efficiency to decrease rapidly. Yet, as shown in applicants' Figure 7, by writing the convex microlenses as concavities, rather than convexities, the

problem is solved and high focusing efficiencies can be achieved even with large beam widths.

The amendments to Claim 1 set forth above are directed to this difference between producing convex microlenses by writing concavities versus writing convexities. Thus, the claim includes the following three subparagraphs, where underlining and strikeouts represent changes introduced by the present amendment:

> (A) said microlens array comprises only ~~at least two~~ convex microlenses at adjacent unit cells so that the photoresist master and the further master if produced comprises only ~~at least two~~ concavities at adjacent unit cells;
>
> (B) the microlens array has a focusing efficiency greater than 50 percent; and
>
> (C) the microlens array would have a focusing efficiency of 50 percent or less if prepared by the same direct laser writing process using the same laser beam with the same finite beam width at the photoresist but with the photoresist master being written so as to comprise convexities at adjacent unit cells rather than concavities.

The changes to subparagraph (A) require that the microlens array comprises only convex microlenses and is supported by, for example, original Claim 2 which has been canceled. Added subparagraphs (B) and (C) explicitly recite the improvement which applicants have achieved by writing concavities, rather than convexities, in a positive photoresist. These paragraphs are supported by, inter alia, equations (1) and (2) and Figures 6 and 7, as well as the text of applicants' specification which discusses those equations and figures.

In particular, Figures 7A and 7B, and the text describing those figures, support the 50% numerical limitation of subparagraphs (B) and (C). As reported in applicants' specification "[t]he estimated efficiency for each microlens in this array [i.e., the array of Figure 7A] is 50%" while the "array [of Figure 7B] is estimated to be 100% efficient in focusing." (See page 12, line 25, to page 13, line 6, of applicants' specification.) Subparagraphs (B) and (C) are based on this switch from 50% focusing efficiency for convex writing to above 50% focusing efficiency for concave writing. Added

independent Claims 30, 34, and 38 have the same format as amended independent Claim 1, but with larger numerical limitations on focusing efficiency, namely, 75, 85, and 95 percent, respectively. These focusing efficiency values are supported by, for example, page 5, lines 6-9, of applicants' specification. Dependent Claims 31-33, 35-37, and 39-41, which depend from the added independent claims, are copies of applicants' original dependent Claims 5-7.

Applicants' amended and added claims are believed to fully distinguish applicants' invention from the prior art, including WO 99/52105 which was newly cited by the Examiner at the July 7th interview. Thus, WO 99/52105 is concerned with the production of data storage disks, not microlens arrays. As such, the reference is totally unconcerned with focusing efficiency. Indeed, the structures it discloses are intentionally widely separated from one another which in a microlens array would reduce, rather than increase, focusing efficiency.

As to Bradley et al. '186 (U.S. Patent No. 4,767,186) and Cowan '216 (U.S. Patent No. 4,496,216), referred to by the Examiner in the July 7th Interview Summary, Bradley has no disclosure regarding direct laser writing and Cowan is another example showing exposure of a photoresist with an interference pattern. Accordingly, like the Hutley article in the Journal of Modern Optics relied on by the Examiner in the March 22nd final Office Action, Cowan '216 is not concerned with direct laser writing. Applicants' claims, on the other hand, each explicitly require direct laser writing.

As to the references cited in the March 22nd final Office Action, only the Gale chapter in the Herzig text (i.e., Chapter 4 entitled "Direct Writing of Continuous-relief Micro-optics," Reference 49 of Applicants' 12/26/01 Modified PTO 1449 Form) and the Gale et al. patent (U.S. Patent No. 4,464,030, Reference 14 of Applicants' 12/26/01 Modified PTO 1449 Form) are specifically concerned with direct laser writing of microlens arrays. The Gale chapter includes Figure 4.11, which is discussed above in connection with the problem of scan lines. It also includes a discussion of the use of small spot sizes to achieve profile fidelity (see pages 90 and 96-101).

The Gale et al. '030 patent discloses a spacing between scan lines of "between 0.5-1 μm, which is slightly smaller than the diameter of focused light spot 130, so that adjacent line exposures overlap to give a smooth final profile" (Gale et al. '030 at column 5, lines 26-30). Although the profiles produced by laser beams of this size can be globally smooth, locally such small laser beams produce scan lines of the type shown in Exhibit C to the Morris Declaration and thus scatter light.

The Gale et al. patent also describes a "two-pass technique" using a 5 μm spot followed by a 1 μm spot (Gale et al. '030 at column 9, lines 19-39). This two-pass approach was developed to address the "diverging requirements" of "the smallest possible focus...to expose a sharp edge between individual lenslets" versus "a large focus, which leads to overlapping exposures between adjacent scan lines" and thus "a smoother surface" (Gale et al. '030 at column 9, lines 9-15).

Significantly, with regard to the present invention, there is no recognition in the Gale et al. patent or the Gale chapter that small spot sizes are <u>not</u> needed if one writes a convex microlens array as <u>concavities</u> in a positive photoresist, as applicants discovered and are claiming. In sum, rather than anticipating or rendering obvious applicants' invention, the Gale references show how the art was stymied by the problems associated with producing convex microlens arrays using direct laser writing.

At the July 7th interview, the Examiner's rejections under 35 USC §112 were also discussed. The Examiner explained that Brueck et al., U.S. Reissue Patent No. 36,113, had been cited for its disclosure of changing the angle between a laser beam and a vertical axis, i.e., angle A in Brueck et al.'s Figures 1 and 2, which the Examiner felt might be encompassed by applicants' claim language. By the above amendment, applicants have made explicit that the "relative movement" called for by their claims is between the laser beam's "finite beam width" and the photoresist which is being exposed. Applicants believe that this language addresses the Examiner's concerns regarding the Brueck et al. patent.

Finally, Dr. Morris and Attorney Klee discussed with the Examiner the technique for making a "master" in which a pattern in a photoresist is translated into an

underlying substrate, e.g., a glass substrate, by etching. This well-known approach for making a master from a photoresist pattern is discussed in the Herzig text referred to above (see page 92) and in PCT Patent Publication No. WO 99/64929 (see Reference 48 of Applicants' 12/26/01 Modified PTO 1449 Form at page 6). Applicants' specification cites both these references (see page 4, lines 12-15).

This etching technique does not involve the use of an "intermediate master" and thus applicants respectfully submit that their claims would be unduly limited by the inclusion of such a requirement as suggested by the Examiner in the March 22nd final Office Action. Applicants note that their claims require that both the "photoresist master" and the "further master," if produced, have "a surface configuration which is substantially the negative of the surface configuration of the microlens array." Thus, there is no question that the master used to produce the microlens array is a negative master, whether it be the photoresist master and/or a further master.

The foregoing amendments and comments are believed to put this application in condition for allowance. Accordingly, reconsideration and the issuance of a notice of allowance for the application are respectfully requested.

Respectfully submitted,

Date: 7/22/04

Maurice Klee

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[253] Attorney Docket No. : RPC-6US

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	:	Geoffrey B. Gretton, G. Michael Morris and Tasso R. M. Sales
Serial No.	:	09/918,257
Filed	:	July 30, 2001
For	:	MICROLENS ARRAYS HAVING HIGH FOCUSING EFFICIENCY
Examiner	:	M. Angebranndt
Group	:	1756

DECLARATION UNDER 37 CFR §1.132 OF G. MICHAEL MORRIS

I, G. Michael Morris, declare as follows:

1. I am an inventor of the subject matter of the above-identified patent application. Attached hereto as Exhibit A is a copy of my curriculum vitae (CV) which sets forth my experience and training in the field of optics including the fabrication of microstructures, such as, microlens arrays. As indicated in my CV, I am presently the Chief Executive Officer of RPC Photonics Inc. (RPC), which is a licensee and has a financial interest in the above-identified application.

2. I have reviewed the Office Action issued by the United States Patent and Trademark Office on March 22, 2004 regarding the above-identified application, as well as the prior art references cited in that Office Action. I also attended the interview with Examiner Angebranndt which took place in the Patent and Trademark Office on July 7, 2004. I make this Declaration in support of an Amendment being submitted herewith in response to the March 22nd Office Action.

3. Attached hereto as Exhibits B and C are copies of the photomicrophraphs of microlens arrays that I showed to Examiner Angebranndt during the July 7th interview. Exhibit B shows microlenses produced using the technique of the above-identified application, while Exhibit C shows a prior art microlens array. Specifically, Exhibit C is an enlarged version of the photomicrograph which appears in Figure 4.11 of Micro-Optics: Elements, systems and applications, Hans P. Herzig, ed., Taylor & Francis, Bristol, PA, 1997. This microlens array was produced by colleagues of mine at Rochester Photonics Corporation. The scan lines which can be seen in Exhibit C are the result of the use of a small beam width to write the microlens array of this exhibit. Such scan lines scatter light during use of the microlens array, thus deminishing the array's effectiveness. The microlens arrays of Exhibit B do not include such scan lines because they were produced using a larger beam diameter, with fidelity of the lens profiles being achieved by writing the arrays as concavities in a positive photoresist.

4. Attached hereto as Exhibit D is a reprint of the cover story of the June 2004 issue of Photonics Spectra, which summarizes some of the commercial applications of the techniques disclosed in the above-identified application.

5. Attached hereto as Exhibit E is a plot of predicted focusing efficiency versus beam width for a microlens array of the type shown in Figure 7 of the above-identified application. This plot was prepared under my direction and supervision at RPC using equations (1) and (2) of the above-identified application, i.e., the equations:

$$F(x,y)=\iint_S f(x',y')g(x'-x,y'-y)\,dx'dy', \text{ and} \tag{1}$$

$$\eta = \left(\frac{B}{A}\right)^2 \times 100\%, \tag{2}$$

and the following standard mathematical form for a Gaussian laser beam

$$g(x) = e^{-8x^2/w^2}$$

where w is the full width of the beam at $1/e^2$.

6. For f in equation (1), a section of a parabola having a chord of 50 microns and a depth of 25 microns was used based on the 50 micron diameter of the microlenses of Figure 7 and the depth of approximately 25 microns shown in that figure. In equation (2), A was 50 microns and B was taken as the point of 5% deviation between the desired curve and the final curve, i.e., B was taken as the diameter over which the ratio of the final surface shape F to the desired surface shape f remained above 0.95.

7. The inserts which appear on the graph of Exhibit E show plots like those of Figure 6 of the above-identified application for representative beam widths of 15, 20, 25, and 30 microns. As can be seen from these inserts, for convex microlenses written in a positive photoresist as convexities, the deviations between desired and final surface shape increase as the beam width increases causing the focusing efficiency to decrease rapidly. As shown in Figure 7B of the above-identified application, by writing convex microlenses as concavities, rather than convexities, the problem of large deviations between desired and final surface shapes with large beam widths can be solved and high focusing efficiencies can be achieved.

8. I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true;

and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

7/22/04
(Date)

G. Michael Morris
G. Michael Morris

July 22, 2004

GEORGE MICHAEL MORRIS
Curriculum Vitae

ADDRESS

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330 Clay Road
Rochester, New York 14623

Phone: (585) 272-2840
Fax: (585) 272-2845
e-mail: morris@RPCphotonics.com

EDUCATION

Ph.D., Electrical Engineering, California Institute of Technology, Pasadena, California; June 1979. Thesis Topic: Serrated Apertures: Statistical Diffraction Theory and Experiments. Advisor: Professor Nicholas George.

Description of Thesis Research: Diffraction of monochromatic light by rough apertures was analyzed. Correlation functions for the electric field and intensity that are valid for large and small roughness were calculated. Measurements in the optical transform plane were used to determine edge roughness and correlation length. Edge roughness was established from transform plane measurements along the central spike. Measurements of the scattered energy perpendicular to the central spike were Fourier transformed to determine the functional form of the correlation coefficient for the rough edge. To verify theoretical predictions, experiments were performed using edges with controlled roughness and correlation length; these edges were generated using computer graphics techniques.

M. S., Electrical Engineering, California Institute of Technology, Pasadena. California; June 1976. The Institute of Optics, University of Rochester, September 1977 to May 1979; on leave from the California Institute of Technology.

B. S., with Special Distinction in Engineering Physics, University of Oklahoma, Norman, Oklahoma; May 1975.

PROFESSIONAL EXPERIENCE

Chief Executive Officer, Apollo Optical Systems LLC and RPC Photonics, Inc., Rochester, New York, January, 2003 - Present

Chief Executive Officer, Corning Rochester Photonics Corporation, Rochester, New York, February 1999 – December 2002.

Chief Executive Officer and Co-Founder, Rochester Photonics Corporation, Rochester, New York; August 1989 - February 1999.

Adjunct Professor of Optics, The Institute of Optics, University of Rochester, Rochester, New York, January 2002 – June 2003.

Professor of Optics, The Institute of Optics, University of Rochester, Rochester, New York, June 1992 - December 2001.

Associate Professor of Optics, The Institute of Optics, University of Rochester, Rochester, New York; July 1985 - May 1992.

Assistant Professor of Optics, The Institute of Optics, University of Rochester, Rochester, New York; July 1982 - June 1985.

Scientist in Optics, The Institute of Optics, University of Rochester, Rochester, New York; July 1979 - June 1982.

Design Engineer, Flo-Bend, Inc., Sand Springs, Oklahoma; June - August 1975.

PROFESSIONAL ACTIVITIES

General Chairman, SPIE Conferences on "Advances in Optical Information Processing," Proceedings Vol. 388, January 1983

Session Chairman, SPIE conference on "Spatial Light Modulators," Proceedings Vol. 465, January 1984

Program Chairman, Rochester Section of the Optical Society of America, 1983/1984

General Chairman, OSA Topical Meeting on Quantum-Limited Imaging and Image Processing, Honolulu, Hawaii, March 31 - April 2, 1986

Councilor, Rochester Section of the Optical Society of America, 1986/1987

Presider, "Exploitation of Invariants in Image Processing," 1986 Annual Meeting of the Optical Society of America, October, 1986

Member, CLEO'87 Program Committee

Co-Chairman, SPIE Conference on "Holographic Optics: Design & Applications," Proceedings Vol. 883, January 1988

Member, Education Council of the Optical Society of America, 1988 - 1990

General Chairman, SPIE Conference on "Statistical Optics," Proceedings Vol. 976, August 1988

General Chairman, ECO2/1989 Paris Conference on "Holographic Optics II: Principles and Applications," Proceedings Vol. 1136, April 1989

General Chairman, ECO4/1991 Hague Conference on "Holographic Optics III: Principles and Applications," March 11-15 1991

Presider, "Symposium on Novel Applications of Diffractive Optics," 1989 Annual Meeting of the Optical Society of America, October, 1989

Presider, "Glass Integrated Optics II," 1990 Annual Meeting of the Optical Society of America, November, 1990

Presider, "Symposium on Holographic Technologies and Applications: 1, 1991 Annual Meeting of the Optical Society of America, November 1991

Organizer, Rochester Science Educators' Day, Optical Society of America, Rochester Section, May 8, 1991

General Chairman, OSA Topical Meeting on "Diffractive Optics: Design, Fabrication, and Applications," New Orleans, LA, April 13-15, 1992

President-Elect, Optical Society of America, Rochester Section, 1989/90

President, Optical Society of America, Rochester Section, 1990/91

Member of Ad Hoc JOSA A Review Committee, Optical Society of America, 1991

Past-President & Education Chair, Optical Society of America, Rochester Section, 1991/92

Member, Committee on Next Generation Currency Design, National Research Council, 1992/93.

Chair, Holography Technical Group, Optical Society of America, 1992/93.

Chair, 1993 Fraunhofer Award Selection Committee, Optical Society of America

Instructor, OSA Short Course on "Diffractive Optics Technology," 1993, 1994, 1996, 1997

Chair, Optical Information Processing Division, Optical Society of America, 1994/95

Chair, 1996 Annual Meeting of the Optical Society of America, Rochester, New York, October 20-25, 1996

Chair-Elect, Technical Council, Optical Society of America, 1997

Chair, Technical Council, Optical Society of America, 1998-1999

Member, Board of Directors, Optical Society of America, 1998-1999

Topical Editor, Applied Optics, Information Processing Division, 1991-1997

Vice President, Optical Society of America, 2001

President Elect, Optical Society of America, 2002

President, Optical Society of America, 2003

Immediate Past President, Optical Society of America, 2004

Member of Editorial Board, Journal of Modern Optics, 1991-1996

Member of Editorial Board, Applied Optics and Optical Engineering Series, Academic Press

Member of Fraunhofer Award Selection Committee, Optical Society of America, 1991-94

Member, Fredrick Ives Medal/Quinn Endowment Selection Committee, Optical Society of America, 2004-05

Member, Joint Advocacy for Optics and Photonics Committee, OSA & SPIE, 2003-2004.

Member, Strategic Planning Committee, Optical Society of America, 2002-2004.

Topical Editor, Applied Optics, Information Processing Division, 1991-1997

Member, OSA Nominating Committee, 1995

Member, OSA Edwin Land Medal Committee, 1995-98

Member, Program Committee, OSA's Topical Meeting on "Diffractive Optics: Design, Fabrication, and Applications," Rochester, NY, June 1994

Member, Program Committee, OSA's Topical Meeting on "Diffractive Optics and Micro-Optics Technology," Boston, MA, April 1996

Fellow, Optical Society of America (OSA)

Fellow, Society of Photographic and Instrumentation Engineers (SPIE)

Reviewer, Journal Optical Society of America, Applied Optics, Optics Letters, Optical Engineering, Optical Communications, Applied Physics Letters, Journal of Applied Physics, Nature, National Science Foundation, Army Research Office, National Institute of Health, New York State Science and Technology Foundation

COMMUNITY INVOLVEMENT

Organizer, Rochester Science Educator's Day, Optical Society of America, Rochester Section, 1991 and 1993. Approximately 75-80 teachers from the Greater Rochester Area attended each event.

Faculty Coordinator, United Way Campaign, University of Rochester, 1995.

Merit Badge Councilor and Assistant Scout Master, Boy Scouts of America, Troop 208, Fairport, NY, 1996 - Present (Eagle Scout, Tulsa, Oklahoma, 1967)

Member, First United Methodist Church, Fairport, NY.

Member and Past Master, Fairport Flower City Masonic Lodge No. 476.

Member and Officer, Ancient and Accepted Scottish Rite, Valley of Rochester

Member, Damascus Shriners, A.A.O.N.M.S. of Webster, NY

Member, Monroe County Workforce Development Steering Committee, 1997.

UNIVERSITY SERVICE

1981/82	Participated in the design of the Undergraduate Teaching Laboratory in Optics, and in the funding campaign for equipment for the facility
1983/84	Member of Research Facilities Committee, College of Engineering and Applied Science
1983/84	Chairman of Optics Computer Committee, The Institute of Optics
1984/85	Colloquium Chairman, The Institute of Optics, University of Rochester
1984/85	Member of Administrative Committee, College of Arts and Sciences, University of Rochester
1984/87	Member of the Optics Undergraduate Committee. Advisor: Senior Class. -- 1986/87
1984/87	Member of the Space and Facilities Committee, The Institute of Optics, University of Rochester
1984/88	Member of Administrative Committee, College of Engineering and Applied Science, University of Rochester
1987/92	Chairman, Optics Undergraduate Committee
1990/91	Member, Long Range Planning Committee, The Institute of Optics
1991/95	Member, Academic Computing Executive Committee
1993/95	Member, Graduate Admissions Committee, The Institute of Optics
1993/95	Member, Faculty Senate
1993/94	Secretary, Executive Committee of the Faculty Senate
1994/95	Chair, Faculty Search Committee
1996	Chair, Search Committee, Allyn Chair in Medical Optics
1997/99	Undergraduate Advisor, Class of 2001 (Optics Freshman)
1998/99	Member, Graduate Admissions Committee, The Institute of Optics

COURSES TAUGHT

1982/83	Opt. 256 -	Optics Laboratory
	Opt. 225 -	Opto-Electronics II
1983/84	Opt. 453 -	Radiation and Detectors
	Opt. 261 -	Physical Optics I
1984/85	Opt. 453 -	Radiation and Detectors
	Opt. 261 -	Physical Optics I
1985/86	Opt. 256 -	Optics Laboratory
	Opt. 492 -	Statistical Optics
1986/87	Opt. 453 -	Radiation and Detectors
	Opt. 261 -	Physical Optics I
1987/88	Opt. 563 -	Statistical Optics
	Opt. 261 -	Physical Optics I
1988/89	Opt. 262 -	Electromagnetic Theory
	Opt. 261 -	Physical Optics
1989/90	Opt 262 -	Electromagnetic Theory
	Opt 492 -	Diffractive Optics
1990/91	Opt 262 -	Electromagnetic Theory
1991/92	Opt 492 -	Diffractive Optics
	Opt 592 -	Diffractive Optics
	Opt 100 -	Introduction to Optics
1992/93	Opt 492 -	Diffractive Optics
	Opt 592 -	Diffractive Optics
	Opt 100 -	Introduction to Optics
1993/94	Opt 492 -	Diffractive Optics
	Opt 592 -	Diffractive Optics
	Opt 100 -	Introduction to Optics
1994/95	Opt 492 -	Diffractive Optics
	Opt 592 -	Diffractive Optics
	Opt 100 -	Introduction to Optics
1995/96	Leave of Absence	

1996/97	Opt 261	- Interference and Diffraction
1997/98	Opt 469	- Diffractive Optics
	Opt 592	- Diffractive Optics
	Opt 261	- Interference and Diffraction
1998/99	Opt 469	- Diffractive Optics
	Opt 261	- Interference and Diffraction
1999/2000	Opt 469	- Diffractive Optics
	Opt 261	- Interference and Diffraction

THESIS TOPICS SUPERVISED
Completed Thesis Topics

Ph. D.

Chris Brophy, Speckle in the Achromatic Fourier Transform Plane, Ph.D., 1984.

Joseph Marron, Statistical Properties of Laser Speckle, Ph.D., 1986.

Doo Jin Cho, Dead-Time Effects in Photon-Counting Detectors, Ph.D., 1989.

Anthony J. Martino, Monte Carlo Optical Computing, Ph.D., 1989.

Thomas A. Isberg, Quantum-Limited Image Recognition, Ph.D., 1989.

Miles N. Wernick, Classification Techniques for Quantum-Limited and Classical-Intensity Images, Ph.D., 1989.

Dean Faklis, Effects and Control of the Correlation Properties of Light Sources, Ph.D., 1990.

Lenore Pugliese, Image Processing and Computer-Generated Holography in Photorefractive Materials, Ph. D., 1990.

Dale A. Buralli, Diffractive Optics: Design Principles and Applications, Ph.D., 1991.

Edward A. Watson, Thermal Imaging with Photon-Counting Detectors, Ph.D., 1991.

Kevin E. Spaulding, Achromatization of Integrated Optical Components using Diffractive Elements, Ph. D., 1992.

Lennard Saaf, Feed Forward Neural Networks for Image Classification, Ph.D., 1992.

Daniel Raguin, Subwavelength Structured Surfaces: Theory and Experiments, Ph.D 1993.

Donald Miller, Imaging Through Aberrated Media and Its Application to High-Resolution Fundus Imaging, Ph.D., 1995.

Song Peng, Polarization Control and Narrowband Filters Based on Subwavelength Structured Surfaces, Ph.D., 1996.

Scott Norton, Resonant Grating Filters, Ph.D., 1997.

Tasso Sales, Phase-Only Superresolution Elements, Ph.D.1997.

Kevin McIntyre, Diffractive Optics Technology for Laser-diode-based Printing Systems, Ph.D., May 1998.

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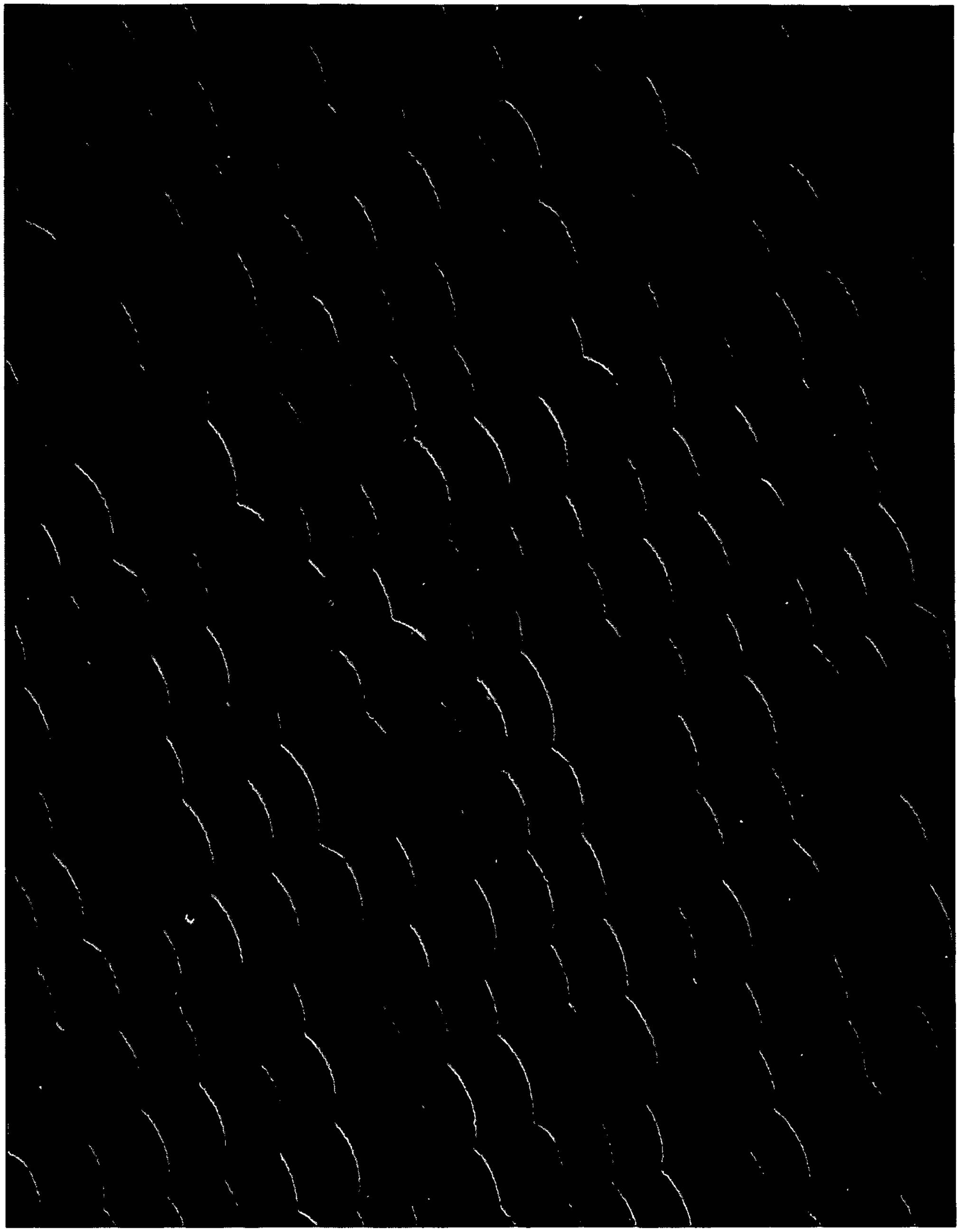
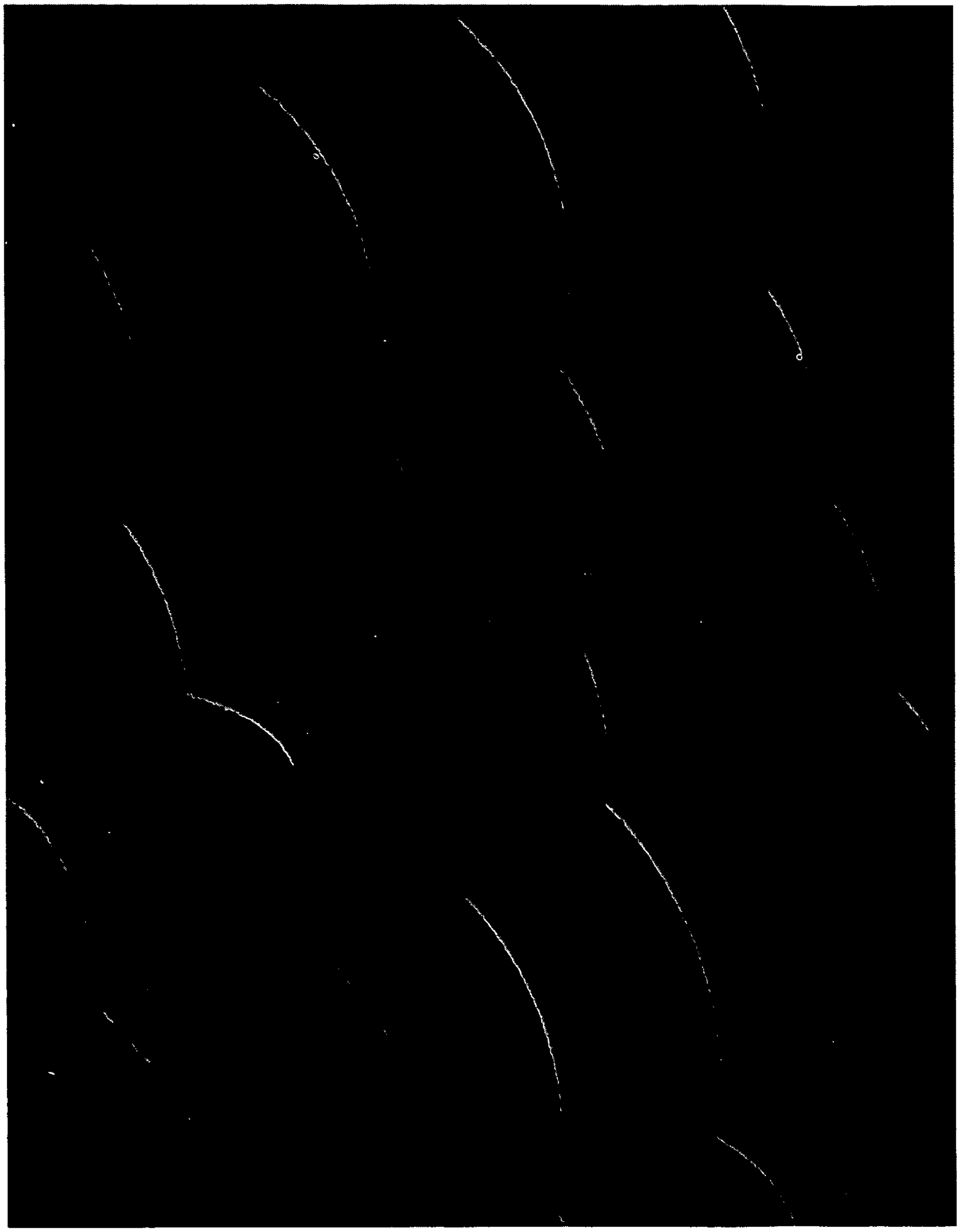
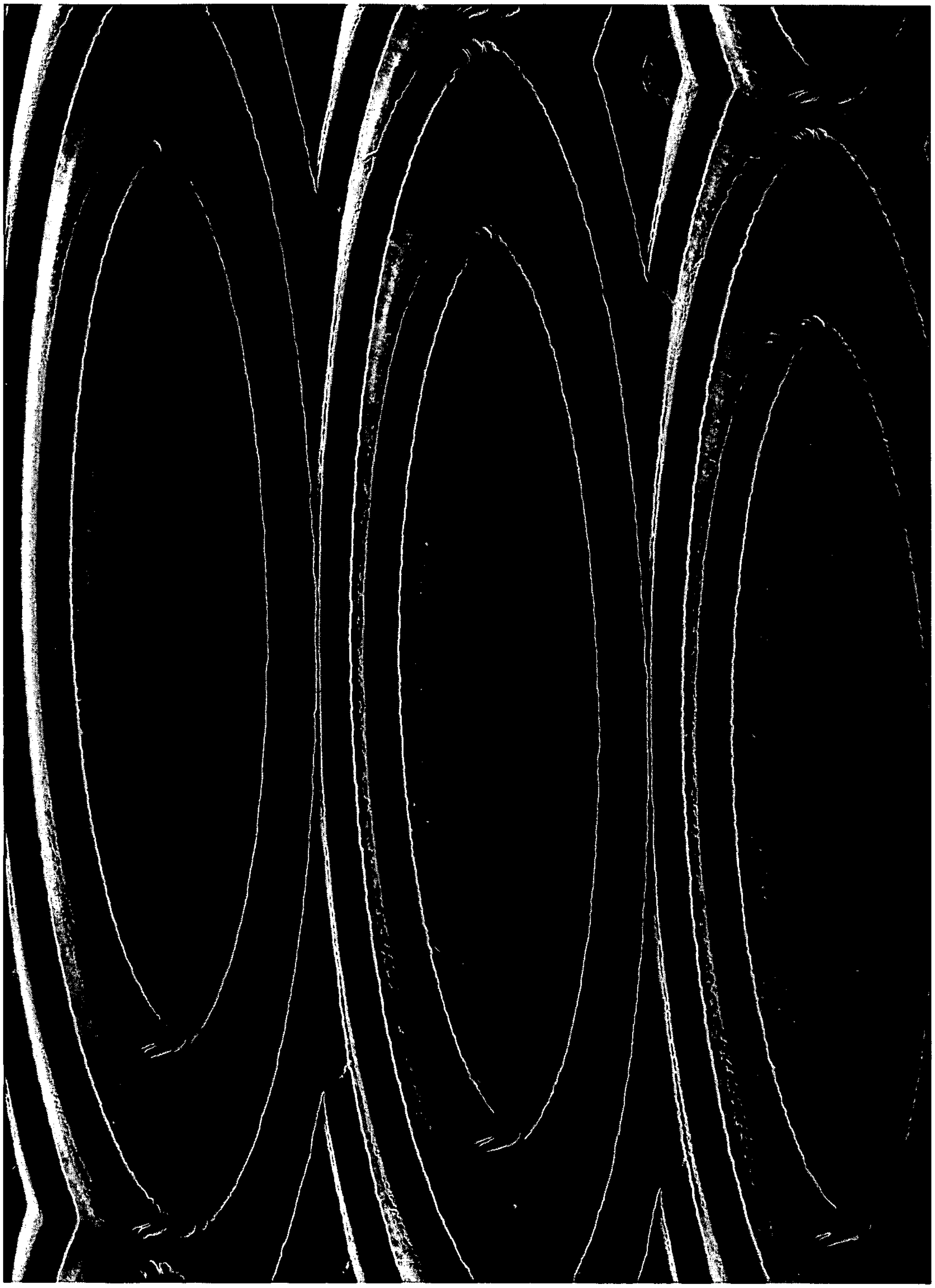
Exhibit B







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PHOTONICS SPECTRA

Light Tamers

Engineered microlens arrays provide new control for display and lighting applications.

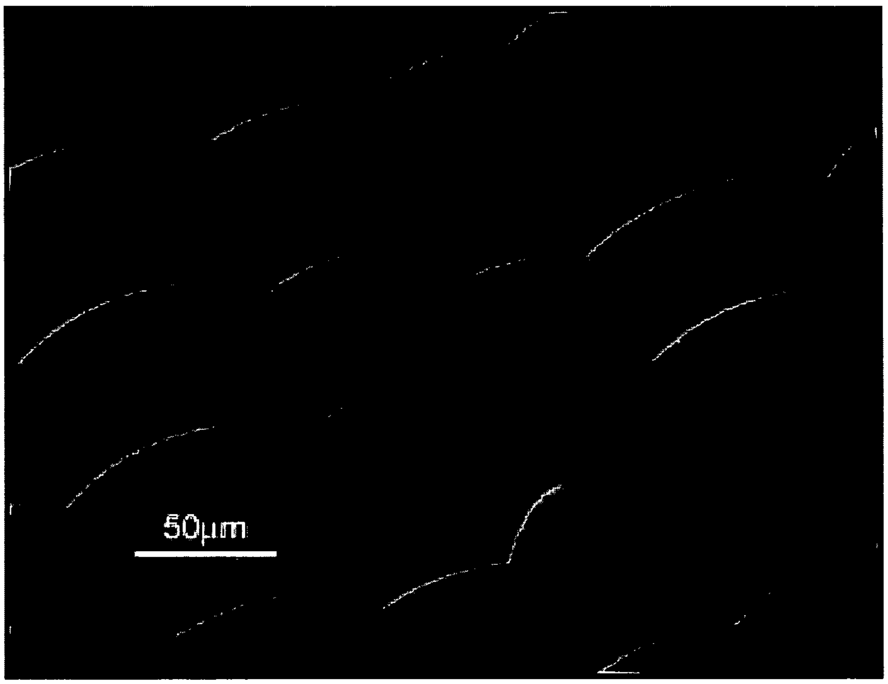
by Tasso R.M. Sales, Stephen Chakmakjian, G. Michael Morris and Donald J. Schertler, RPC Photonics Inc.

From sophisticated deep-UV steppers to indoor-outdoor lighting applications, passing through rear-projection television screens and consumer electronic displays, one finds a common optical component: diffusers.

These devices homogenize and distribute light over a specified region of space. Diffusers are an example of a more general class of components known as beam shapers, whose main purpose is to alter and project an input beam into a useful angular range with controlled intensity distribution.

The advanced diffusion and beam-shaping capabilities of a new class of diffusers make them suitable for most applications that require a homogeneous light distribution with a specified intensity profile and spatial distribution. These applications include laser illumination, projection and display systems, and solid-state lighting.

Commonly used diffuser technologies include prismatic glass integrating bars, ground glass, opal glass, holographic diffusers and diffractive diffusers. Prismatic glass integrating bars, though sometimes used in high-end systems, are very limited in capability, are expensive and occupy a great deal of precious space. Ground and opal glass scatter light equally in all directions but have limited light-control capabilities. These simple diffusers also often offer poor efficiency.



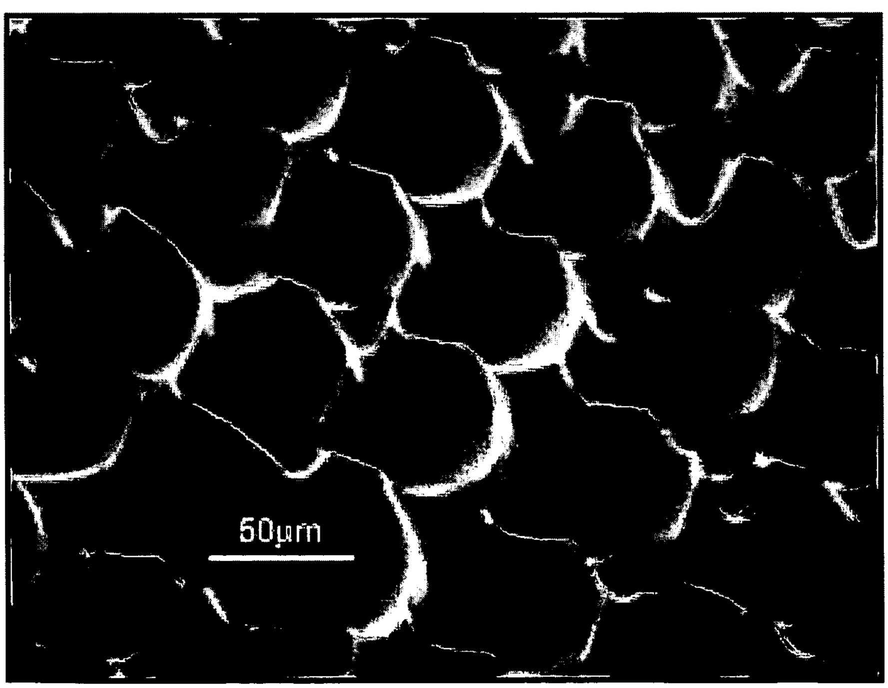


Figure 1. Close-packed arrays of accurately and independently produced microlenses offer some advantages for projection screen applications (top) and display brightness enhancement (bottom).

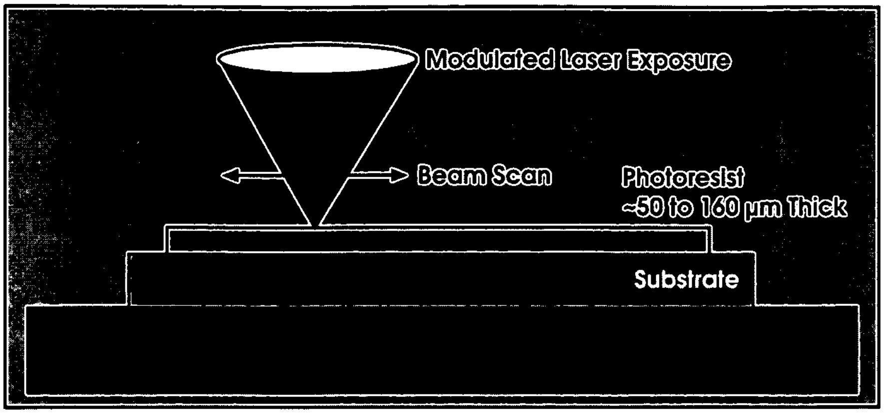


Figure 2. To manufacture the diffusers, a modulated laser exposes a thick photoresist point by point in a raster scan mode with a small focused beam.

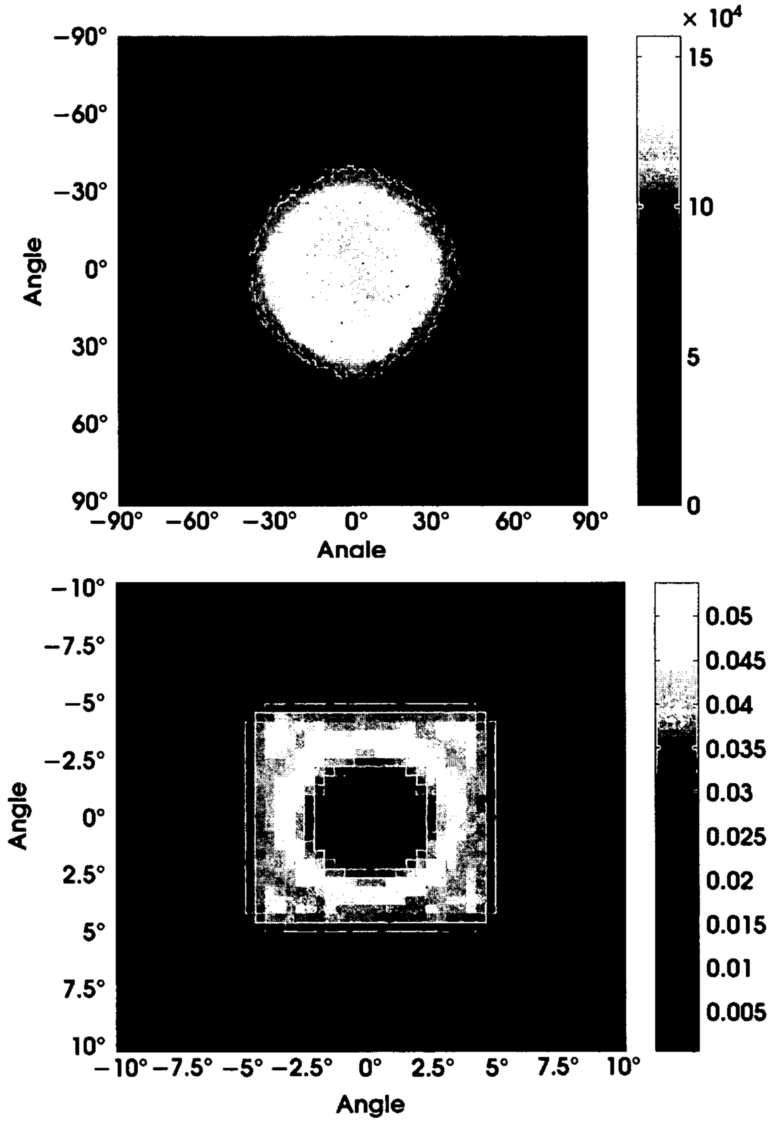


Figure 3. The measured intensity profile from an Engineered Diffuser illuminated with a coherent helium-neon laser beam shows wide, round scatter with a flat intensity profile (top) and square scatter with a center hole (bottom). A source of different wavelength produces the same profile with a slight variation in divergence angle because of the change in the microlens material's index of refraction.

A holographic diffuser, a step ahead of ground glass, enables the production of simple light distribution patterns. However, it has limited control over the light distribution pattern, generally making only round or elliptical patterns with nonuniform intensity variation, typically of a Gaussian nature.

Diffractive elements can, at least in theory, shape an input beam arbitrarily. They are, however, mostly limited to monochromatic applications with coherent light sources. Fabrication requirements limit diffractives to narrow diffusion angles. These elements also can be strongly sensitive to input beam variations, and they present the well-known problem of zero order: a bright spot collinear with the incident beam. In many applications, the zero order is unacceptable, and the requirement of single-wavelength operation very restricting.

New technology

A new diffuser and beam-shaping technology can challenge some of these drawbacks and provide significant performance enhancements for applications such as lithographic systems, efficient solid-state lighting, backlighting, projection screens and displays. This concept, trademarked as Engineered Diffusers, differs from other technologies in numerous ways.

Unlike random diffusers such as ground glass, opal glass and holographic elements, these devices control each scatter center, generally with microlens units. Holographic diffusers, for instance, can be seen as a random arrangement of lenslets. However, the lenslike features are created by the holographic exposure process and are controlled only in a statistical sense: Individual microlens units are not individually manipulated, which helps to explain why holographic diffusers cannot control light distribution and profile.

An Engineered Diffuser individually specifies each microlens unit with respect to its sag profile and its location in the array. Furthermore, to ensure that the diffuser can handle input beam variations and does not produce diffraction artifacts, the

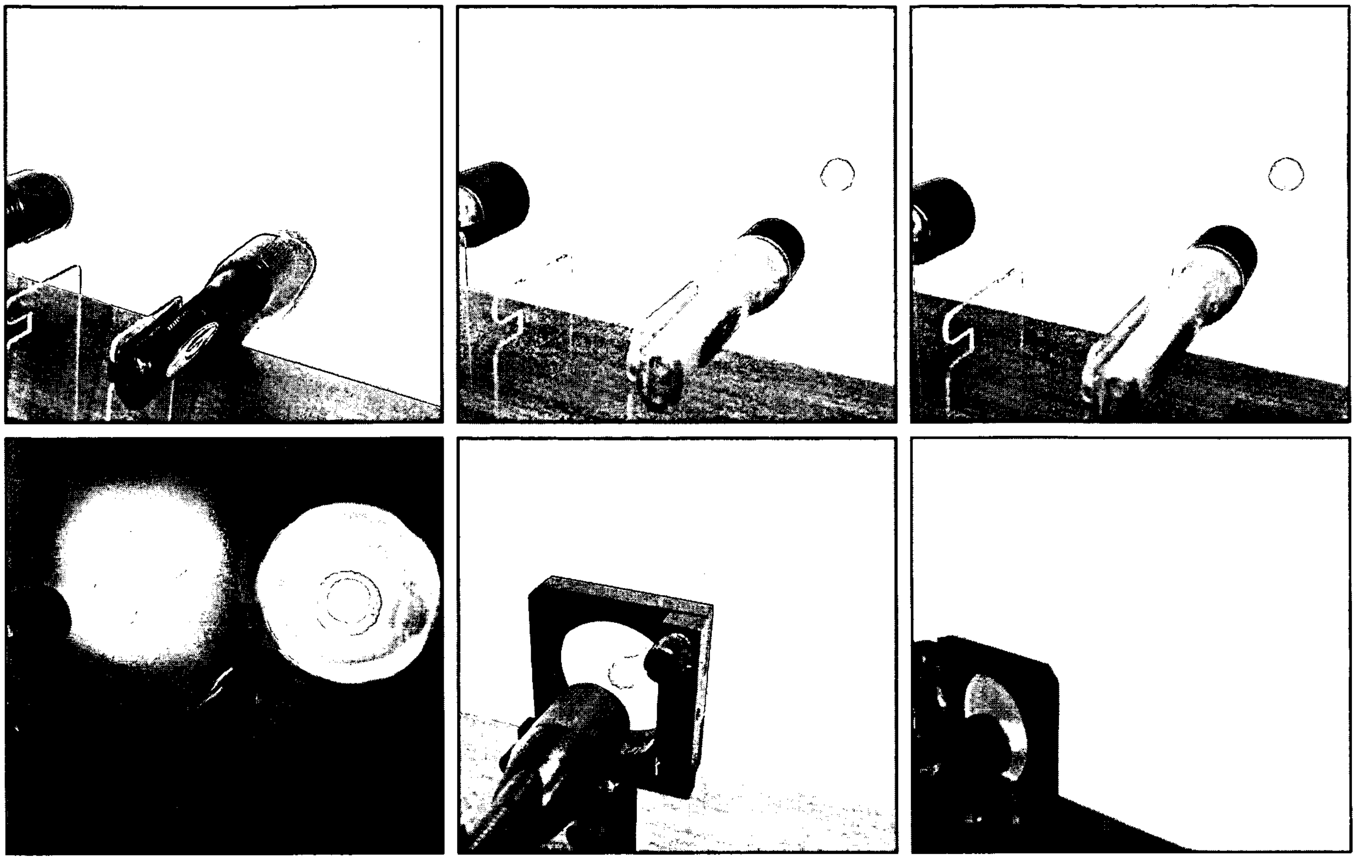


Figure 4. *Diffusers based on new technology perform beam shaping and homogenization of LED light sources.*

distribution of microlenses is randomized according to probability distribution functions chosen to implement the desired beam-shaping functions. Therefore, this device retains the best properties of both random and deterministic diffusers.

Deep, continuous surface

Microlens arrays have provoked continual interest as fabrication capabilities have matured over the years. Some of their applications, such as Shack-Hartmann interferometry, laser-to-fiber coupling and optical switching for telecommunications, have little to do with light diffusion. Still, periodic microlens arrays work in illumination systems with a condenser lens by relying on the source's low coherence and convolution effects.

Periodic microlens arrays are not, strictly speaking, diffusers, and they provide limited beam-shaping capabilities. Even so, most rear-projection TV screens still use them; e.g., lenticular (cylindrical) arrays. To eliminate artifacts from the periodic nature of the array, screen manufacturers add volume and surface diffuser components to homogenize the scatter and to add vertical gain at the cost of reduced resolution and speckle.

At the heart of the Engineered Diffuser technology is the capability to manufacture a close-packed array of accurately and independently produced microlenses, each designed to a unique lens prescription and spatially distributed in an arbitrary fashion (Figure 1). The array maintains a 100 percent fill factor even with variations in the shape of each lens boundary. Furthermore, the manufacturing process can control the diameter of each microlens unit and the relative vertical position of each microlens (piston).

Manufacturing these devices involves processing photoresist materials about 50 to 160 μm thick, much thicker than commonly used in lithography. A laser system[1] exposes thick photoresist point by point in a raster scan mode with a small focused beam (Figure 2). The system modulates the laser beam as it traverses the coated substrate. Developing the photoresist produces a deep, continuous surface.

Despite the innovative processes used in making the diffusers, the cost per piece is comparable to that of components that rely on conventional photolithographic fabrication techniques. The main cost item constitutes the production of the initial photoresist master, in which a laser writing session can take from less than an hour to several days, depending on the required pattern size. The master can then be transferred to more durable material with methods such as etching, replication or nickel electroforming, as dictated by the application. From this point, techniques such as embossing or injection molding can be used to produce volume quantities at costs comparable to those of other diffuser components on the market.

Displays and lasers

Such a microlens array could work in projection screens and enhance

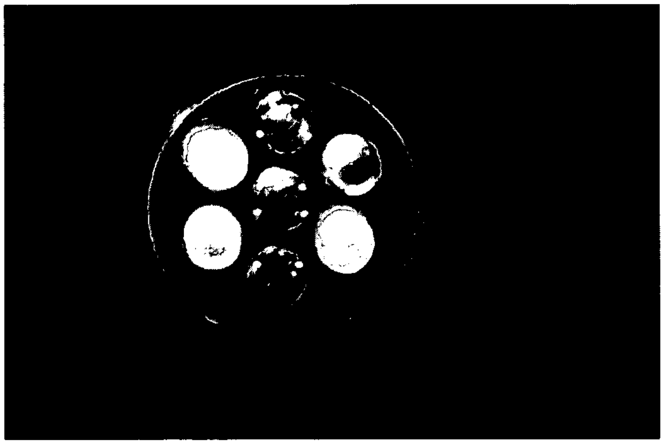


Figure 5. *An Engineered Diffuser simultaneously mixes an RGB LED array (left) and shapes the light into an oval scatter distribution with wider divergence in one direction (right).*

display brightness. Projection screen applications are particularly challenging because they require wide angle divergence — 120° full width at half maximum — in one direction (horizontal) and narrow divergence — 40° FWHM — in the other (vertical), with controlled intensity profiles. Because it is a visual application, a projection screen cannot introduce image or color defects and should not introduce speckle. Also, the screen geometry must incorporate a black-absorbing material to prevent ambient light from reflecting to the viewer, thus maximizing image contrast. Illumination from the light engine transmits through apertures created by the focusing elements of the screen itself.

The Engineered Diffuser enables the design of screens[2] that meet the desired intensity profile within the field of view. Also, it can control the near-field distribution of focus spots to maximize the coverage of black material and to improve contrast. Finally, controlling the size of the microlens units with regard to the light engine's coherence properties avoids speckle while maintaining high resolution.

Controlling individual microlens elements and arbitrarily distributing them in the array enables advanced beam-shaping and features that are not possible with diffractives or any other diffuser technology. For instance, these devices perform equally well under monochromatic or broadband illumination with no zero-order or diffraction artifacts, irrespective of the divergence angles.

An application of particular interest is the shaping and homogenization of laser beams. Most diffuser technologies have little difficulty generating, for example, round diffusion patterns. However, in most cases, the pattern has nonuniform Gaussian intensity profiles (such as the case of ground glass and holographic diffusers) or small divergence angles with some degree of zero order (such as diffractive diffusers). Periodic microlens arrays cannot generate round diffusion, but a hexagonal array can approximate a circle.

Engineered Diffusers, however, can generate round patterns with uniform intensity distribution over any angular range, independent of wavelength (Figure 3). They also can generate more-complex scatter patterns that are usually attainable only with diffractive elements.

LED efforts

An important emergent application for these diffusers is in solid-state lighting. LED-based illumination systems will become more pervasive in applications including displays, signage, architectural lighting and general illumination. Some of the advantages that LED sources offer are longer lifetimes, and cost and energy savings.

Engineered Diffusers address the diffusion and control of LED illumination with efficient distribution of the available luminous energy. In typical cases, the technology can improve the efficiency of solid-state light utilization by a factor of two or more (Figure 4).

For example, they can direct most of the light into specific regions of space, thereby increasing the efficiency of light usage. These targeted light distributions will also be relevant in reducing light pollution and improving the quality and effectiveness of displays by creating effects that would otherwise be impossible to achieve with the raw beam alone or with simple diffusers. Also, the diffusers can mix light from RGB arrays, managing the color temperature by controlling the content of the red, blue and green components, while shaping the mixed light distribution (Figure 5). □

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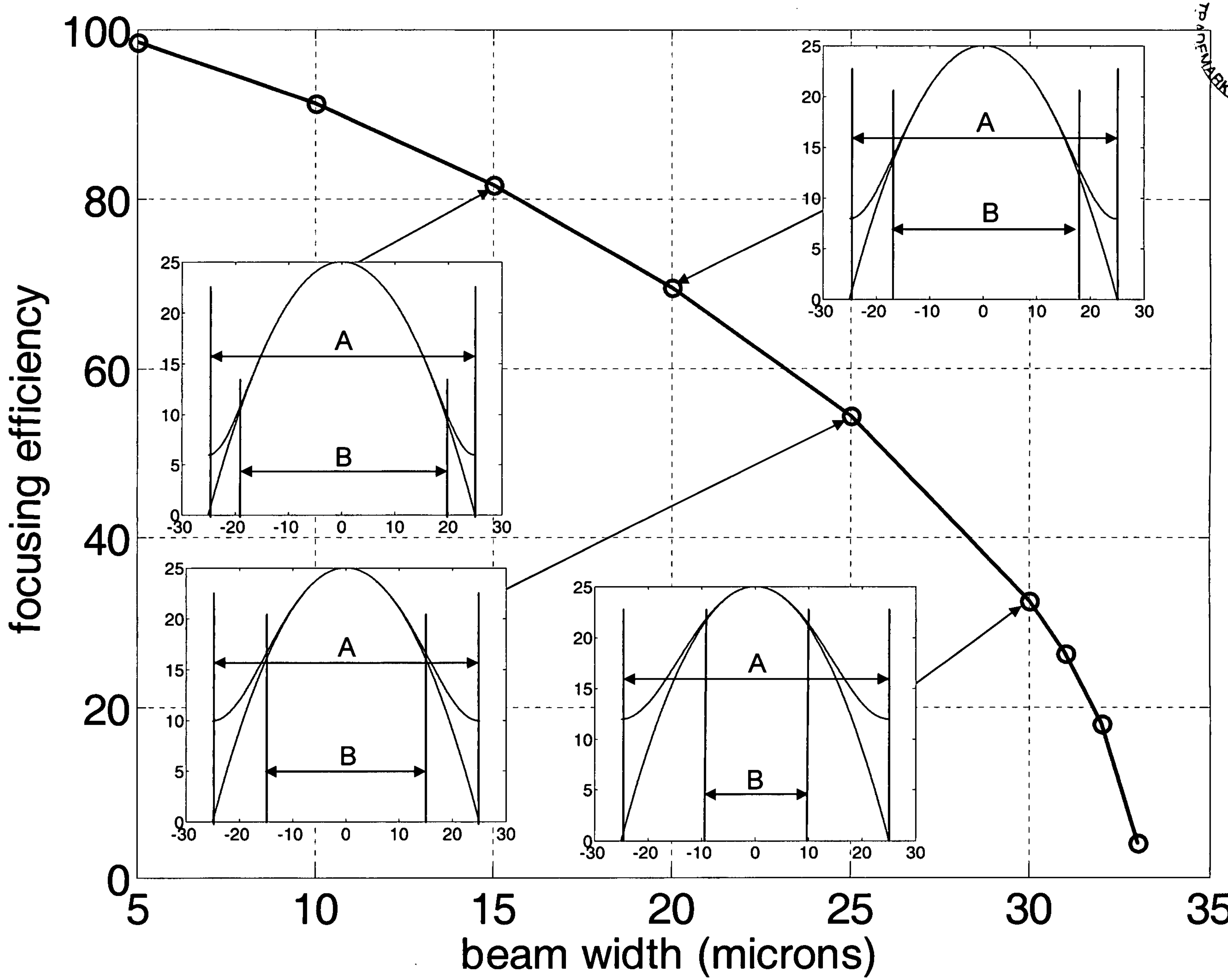

focusing efficiency
beam width (microns)
A
B